

## 2.3 DNA



Have you ever listened to music at an outdoor concert on a warm summer's evening? If you have, can you remember the particular songs or pieces that were played? Depending upon the type of music and the performers, the musicians sometimes memorize the music. In other cases they use sheet music. On one level, a performer who is reading the sheet music is translating the information from the page into a tune or a song. But lovers of music would argue that there is much more to performing than playing the notes in the right order—a good musician is an artist.

To someone who doesn't read music, the symbols used for notes look like simple shapes on a page in random order. The information on a deoxyribonucleic acid (DNA) molecule might also seem like a random arrangement of chemical units, but to the cells in your body this arrangement is a meaningful set of instructions for making essential products. Just like a huge variety of songs can be written on sheet music from a limited number of musical notes, a huge variety of instructions can be encoded on a DNA molecule from a limited number of chemical units. While music is the product that can be produced by playing the notes on sheet music, proteins are the product that can be produced by translating the code on a DNA molecule. These proteins make life possible by forming structural and regulatory molecules within cells.

Understanding how DNA works is a bit like understanding sheet music. First, you need to understand how the symbols are used to represent the sound that each note makes and the rules used in writing music. Once you understand the language of music, then you can look at how the notes are put together for a particular song and can use an instrument to translate written notes into played notes. Recognizing the symbols used to represent the chemical units of DNA and understanding how the DNA molecule is put together are important skills that allow scientists to read and translate this genetic information into the protein products that make up an organism.

In this lesson you will identify the structure and components of DNA. You will learn how to read and translate elementary sections of DNA code and explain the process of DNA replication. Just as there is more to music than playing notes in the correct order, there is more to a full understanding of DNA than learning how to assemble simple structures. Nevertheless, just as some musical training leads to a greater appreciation of a performing artist's skill, your work with DNA will provide you with a new appreciation of the instructions that made you.

## Try This Activity

### Extracting DNA from Wheat Germ

#### Purpose

In this investigation you will extract DNA from raw wheat germ.

#### Materials

- 1 g of raw wheat germ (not toasted)
- liquid detergent
- 95% ethanol (ethyl alcohol) or 70% isopropyl alcohol
- 2 50-mL test tubes with stoppers
- hot tap water (approximately 50–60°C)
- graduated cylinder
- 2 glass stirring rods
- paper towel
- paper clip



#### Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

#### Procedure

**step 1:** Add 20 mL of warm tap water to both test tubes.

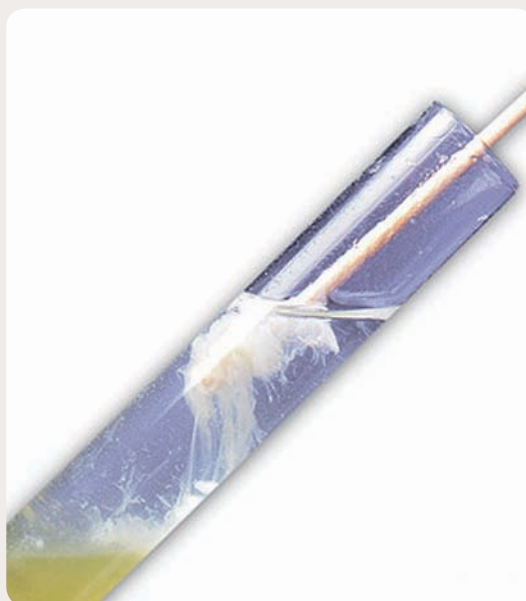
**step 2:** Add 1 g of raw wheat germ to only one of the test tubes. Mix continuously for at least 3 min.

**step 3:** Add 1 mL of liquid detergent to each test tube, and use a glass stirring rod to stir each gently for 5 min, creating as little foam as possible. Vigorous stirring will break up any DNA into smaller pieces, which are more difficult to see.

**step 4:** Use a sheet of paper towel to remove any foam produced.

**step 5:** Tilt the test tubes and slowly pour 14 mL of alcohol down the side of each test tube. The alcohol should form a separate layer on top of the test-tube mixture. Do not stir or mix the two layers.

**step 6:** Let the test tube sit for a few minutes. Extracted DNA will appear as a white filmy substance and should precipitate and clump together at the boundary of the two layers. If you continue to let it sit, the DNA should float to the top of the alcohol or you can use your glass stirring rod or the loop of a partially straightened paper clip to pull the DNA out of the solution.



#### Analysis

1. Explain why you prepared a test tube with wheat germ and then—following the identical procedure—another test tube without any wheat germ.
2. Compare the amount of DNA in the test tube with the wheat germ to the test tube without the wheat germ.
3. Do you think it would be possible to use a similar procedure to extract DNA from other materials such as split-green peas, strawberries, or chicken livers? Explain why.

## The Structure of DNA

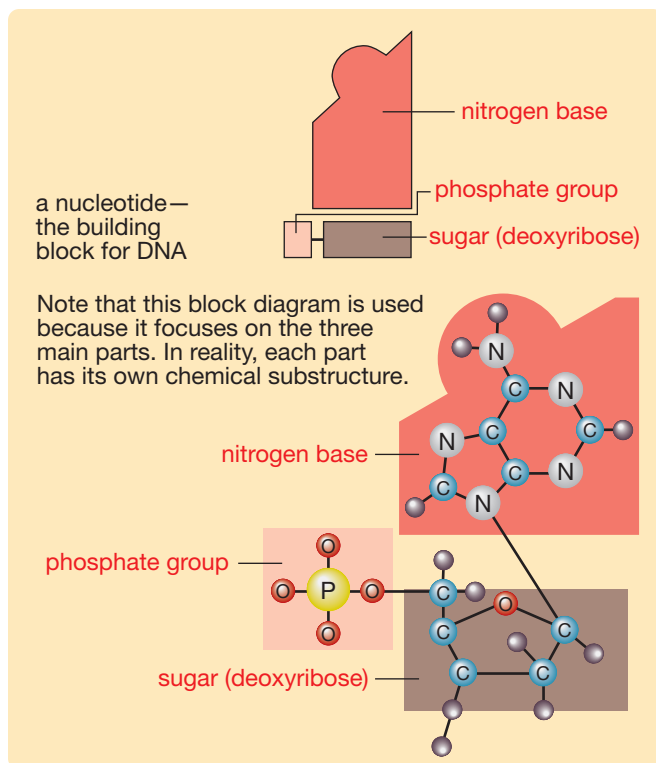
The overall shape of a DNA molecule has been compared to a twisted ladder or a spiral staircase. Just as the spiral staircase in Figure A2.13 was assembled from individual wedge-shaped steps, the DNA molecule is composed of chemical units called **nucleotides**. Each nucleotide contains a phosphate molecule, a sugar called deoxyribose, and one of four nitrogen-base molecules.

► **nucleotide:** a chemical unit consisting of a phosphate molecule, a deoxyribose sugar molecule, and one of the four nitrogen-base molecules—adenine, cytosine, thymine, or guanine

Two complementary nucleotide chains combine to form DNA.

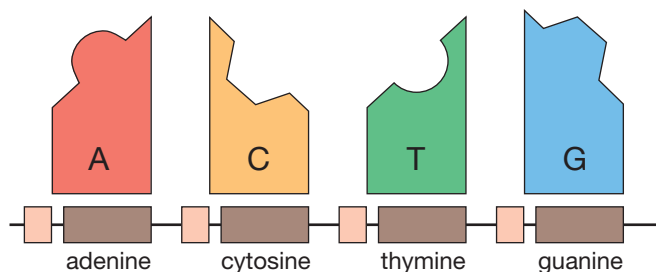


Figure A2.13



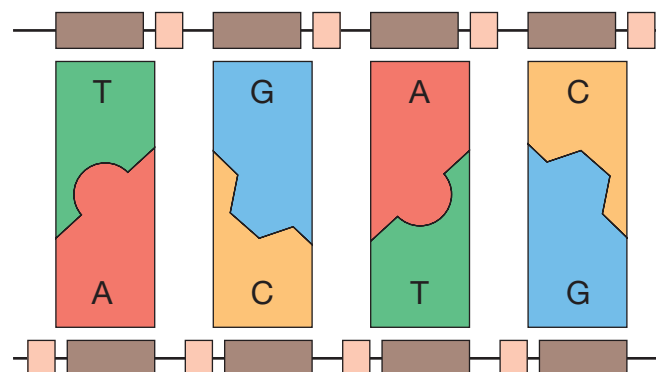
The phosphate and sugar parts of the nucleotide attach to each other to form a repeating chain that makes up the “backbone” of a DNA molecule. The nitrogen base part of the nucleotide sticks out from the sides of this chain. The four nitrogen bases are adenine, cytosine, thymine, and guanine.

The four types of nitrogen bases in nucleotides join to form a single chain—half of a DNA molecule.



These bases are usually abbreviated using the first letter of their name. The long chain of nucleotides can be very long—in this arrangement it makes up half of the DNA molecule. The other half of a DNA molecule is formed from another long chain of nucleotides that attaches to the first strand of nucleotides by hydrogen bonds between the nitrogen bases on opposite strands.

DNA consists of two long chains of nucleotides connected by complementary nitrogen base pairs.

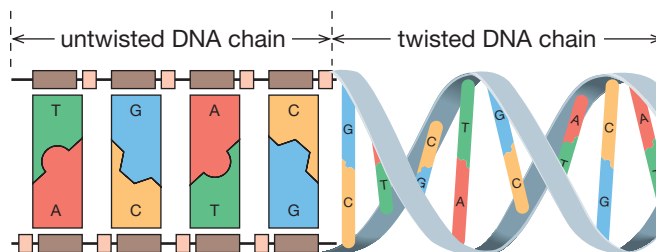


**base pair:** the two nucleotides connected on opposite sides of complementary strands of the DNA molecule

Complementary base pairings for DNA are adenine with thymine and cytosine with guanine.

The four possible bases have a unique chemical structure that allows them to bond only with one other base. When the two bases are bonded together, they are called a **base pair**. Adenine can only bond to thymine and vice versa (A-T or T-A) and cytosine can only bond to guanine and vice versa (C-G or G-C). As a result of the specific bonding between bases, the DNA molecule is comprised of two long chains of nucleotides with bases of one chain paired up with another chain containing complementary bases. For example, if the base pairs on one side of the molecule are ACTGTTA, then the other side of that section of DNA has the complementary base pairs of TGACAAT. The two paired strands form a structure that looks like a twisted ladder, with the base pairs acting like the rungs of the ladder and the sugar and phosphate molecules acting as the ladder’s side. The distinctive coiled shape of DNA, which is similar to the appearance of a spiral staircase or a twisted phone cord, is called a double helix.

The double-helix shape of DNA is made as the two interlocking chains of nucleotides are twisted.





## Utilizing Technology

### Building a DNA Segment



#### Science Skills

✓ Analyzing and Interpreting

#### Purpose

You will build a short segment of the DNA strand by matching up the nitrogen bases in the nucleotides.

#### Procedure

Locate the applet “Building a DNA Molecule” on the Science 30 Textbook CD. Follow the instructions.

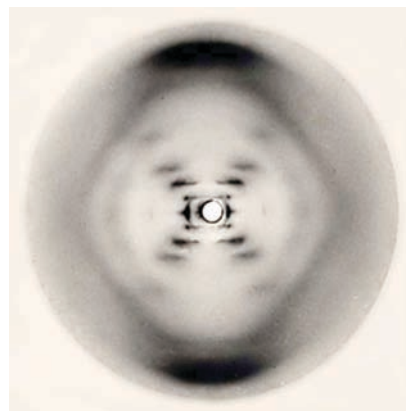


## Discovering the Structure of the DNA Molecule

The discovery of the three-dimensional structure of the DNA molecule is credited to James Watson and Francis Crick. Their description of DNA’s structure was only possible by incorporating the findings of other scientists whose experiments produced unexplained results.

For example, Erwin Chargaff discovered a one-to-one ratio between the bases of adenine and thymine and between the bases of cytosine and guanine. Chargaff could not explain this ratio found in all DNA samples analyzed.

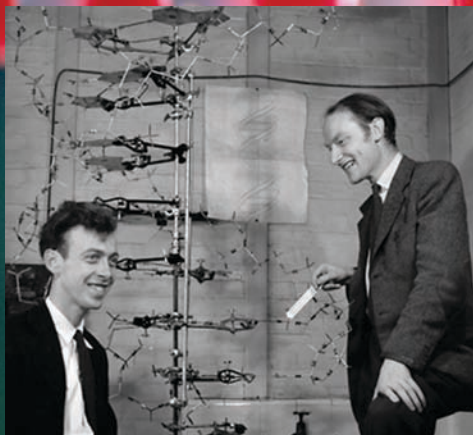
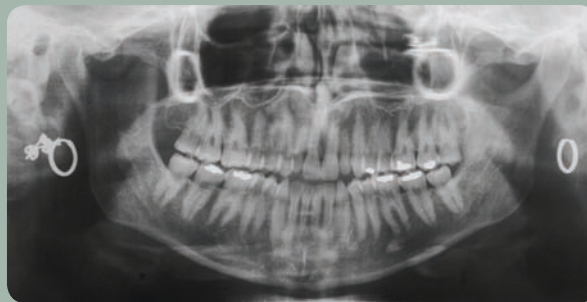
When Rosalind Franklin fired a beam of X-rays at a hair-like thread of DNA, the X-rays changed direction as they encountered the delicate DNA structures. After passing through the DNA, the redirected X-rays created a distinct pattern—coincidentally, the letter X—on photographic film on the other side. Franklin interpreted this photo to mean that the X-rays had encountered a molecule shaped like a helix. She had also discovered that the phosphate part of the molecule was on its outside. Franklin’s supervisor Maurice Wilkins, who began the X-ray research, showed her X-ray picture and the results of her work to Watson and Crick without her knowledge or permission. Watson and Crick were able to use Franklin’s findings to help assemble a working structure.



Franklin died of ovarian cancer in 1958, four years before Watson, Crick, and Wilkins jointly received the Nobel Prize in medicine or physiology for their work on the structure of DNA. The Nobel Prize is awarded only to living scientists.

#### Science Links

In Franklin’s work, the X-rays passed through the DNA but changed direction in the process. This left an interesting pattern on photographic film. When you go to a dentist for teeth X-rays, high energy X-rays are used to create a shadow image of your teeth. Denser areas—corresponding to fillings and jewellery—create shadows on the photographic film placed in your mouth. These shadow areas appear white. You’ll learn more about X-rays and how they are used in Unit C.

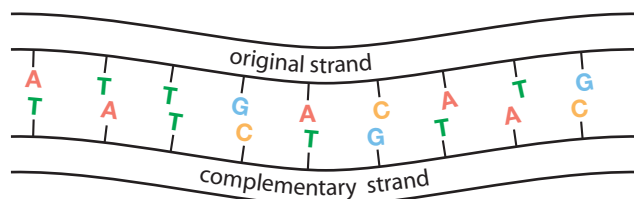




## Practice

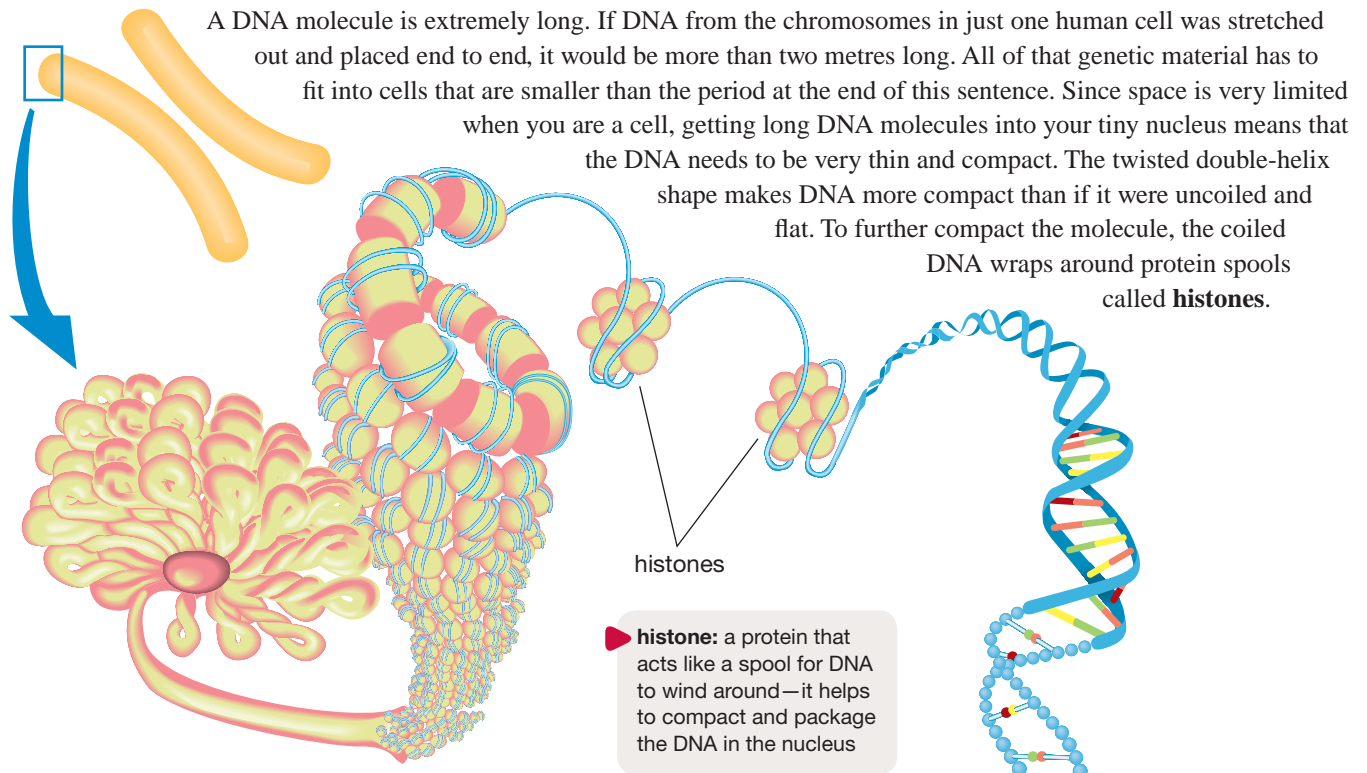
27. The nucleotides are the building blocks of the DNA molecule.
- Sketch the nucleotide that has thymine as its nitrogen base, and label the three distinct parts of the nucleotide.
  - The DNA molecule has been described as a twisted ladder. Add labels to your sketch from question 27.a. to indicate which part(s) of the nucleotide will form the rungs of the twisted ladder and which part(s) will form the long sides.
28. Four types of nucleotides can be identified by the individual nitrogen bases or their abbreviations—adenine (A), cytosine (C), thymine (T), and guanine (G).
- Identify the complementary base pairs that form in a DNA molecule.
  - State the reason why the nucleotides can pair up only in these combinations.
29. Write the base sequence that makes up the complementary strand for the nucleotide sequence of each provided strand.
- AAATGTCGCCT
  - TAGTCTA
  - GATTGATTCCGGGCTAA
30. A student correctly copied down a nucleotide sequence but made a mistake when writing the complementary strand below it. Identify the mistake in the complementary strand.

There is an error in the complementary strand.



- Using what you know about DNA structure, account for the findings of Erwin Chargaff.
- Describe Rosalind Franklin's contribution to the discovery of the DNA molecule's structure.

## Histones—Spools for DNA



In the next investigation you will have an opportunity to explore the advantages of spooling when it comes to packaging long strings of material.

## Investigation

### Packaging DNA

#### Purpose

You will perform a simulation that relates how DNA is packed to fit into the nucleus of a cell, and you will also perform calculations involving DNA length.



#### Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

#### Materials (for each group of students)

- one spool of sewing thread
- scissors
- tape measure or metre-stick
- one size '000' or '00' empty gelatin capsule per group—available at health food and supplement stores

#### Procedure

**step 1:** Imagine that the small gelatin capsule that your group has been given represents an enlarged nucleus.

**step 2:** Measure and cut a piece of thread 10-m long from your group's spool. This piece of thread will represent the DNA from one set of chromosomes that has been unraveled, attached end to end, and enlarged five times.

**step 3:** Your objective is to coil and wrap the thread so that it is compact enough to be inserted into the gelatin capsule and the capsule can be closed.

#### Analysis

1. Was this activity difficult to perform? Were you able to get the thread into the capsule? Could you have put the thread into the capsule without coiling and wrapping it?
2. a. Describe how the method you used to get thread into the capsule is similar to the way DNA is compacted and packaged into the nucleus.  
b. Describe how it is different.
3. Explain some methods or tools that would have made an easier job of getting the thread into the capsule.

#### Calculations

4. The nucleus of an average cell has a radius of about 5 micrometres or  $5.0 \times 10^{-3}$  mm.
  - a. Calculate the volume of a spherical nucleus using the formula for the volume of a sphere:  $V = \frac{4}{3} \pi r^3$ . Express your answer in  $\text{mm}^3$ .
  - b. Measure both the length and radius of your gelatin capsule in millimetres. Use your measurements to calculate the approximate capsule volume by using the formula for the volume of a cylinder:  $V = \pi r^2 L$ . Your teacher may provide the dimensions of the capsule from the bottle.
  - c. Calculate the ratio of how many times larger the capsule you used for the activity is than an actual human cell nucleus. Do this by dividing capsule volume by nucleus volume.
5. It is often stated that within the nucleus of a typical human cell, the total length of all the DNA would be about 2 m if it were stretched out end to end. Use the following information to confirm this statistic:
  - There are two sets of chromosomes in each nucleus.
  - One set of chromosomes has approximately three billion base pairs ( $3.0 \times 10^9$ ).
  - One base pair is approximately 0.34 nanometres in length ( $3.4 \times 10^{-10}$  m).
6. An adult human body has at least 50 trillion cells ( $50 \times 10^{12}$ ). Use this information and your answer to question 5 to determine the total length of all DNA in a human body if it were stretched out end to end.
7. The distance from the Sun to Earth is  $1.5 \times 10^{11}$  m. This is called one astronomical unit or A.U. Calculate the ratio of approximately how many times longer the total length of DNA in a human body is relative to the distance between Earth and the Sun.
8. Consider your answers to questions 4.a., 6, and 7. Comment on these values in light of your struggles to pack 10 m of thread into a gelatin capsule.

One of the best ways to understand the process of copying a strand of DNA is to try a simple pencil-and-paper version yourself. This is what you will be doing in the next activity.

## Try This Activity

### Simulating DNA Replication

#### Purpose

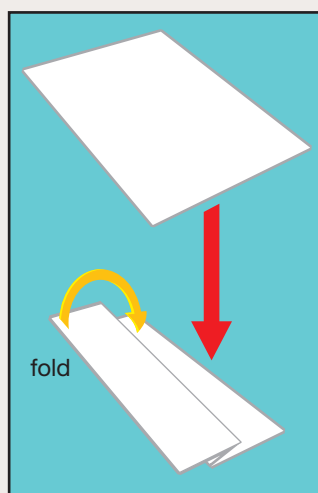
You will use simple materials to simulate the process of DNA replication.

#### Materials

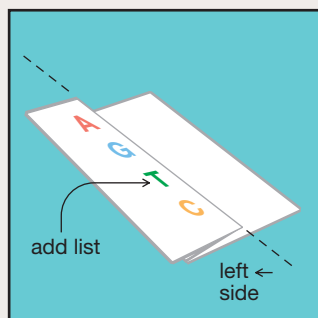
- blank piece of paper
- pencil

#### Procedure

**step 1:** Fold the piece of paper as shown on the following illustration.



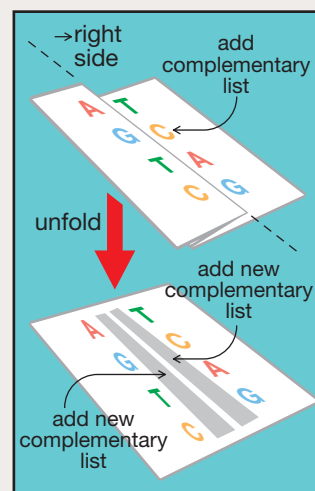
**step 2:** On the left side of the fold, record a random list of 15 nitrogen bases. Use the initials A, C, T, and G to represent each base.



#### Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

**step 3:** On the right side of the fold, record the complementary strand of base pairs to complete the DNA molecule.



**step 4:** Unfold the piece of paper and lay it out flat in front of you so that the two strands of bases are now separated. Add the complementary strand of base pairs to each of the separated strands.

**step 5:** Save the piece of paper to help you answer the "Analysis" questions.

#### Analysis

1. You now have three complete sets of DNA to compare. These are the original strand that can be viewed by re-folding the paper, and the two duplicate strands that can be seen by unfolding the paper and pressing it flat. Compare all three strands of DNA.
2. How do you account for the trends you identified in your answer to question 1?



## DNA Replication

When a cell needs to multiply to aid in the growth or repair of an organism, its DNA must first be copied. It is important that each of the two daughter cells produced during mitosis receives an exact copy of the parent cell's DNA. The process of making an extra copy of DNA for a new cell is called **DNA replication**. This is illustrated in Figure A2.14.

During replication, the two complementary strands of DNA are untwisted, the bonds between the bases are broken, and the strands separate like a zipper being unzipped. This process is controlled and aided by several protein enzymes.

▶ **replication:** the process of making two DNA molecules from one original molecule prior to cell division

The bases of free-floating nucleotides in the nucleus attach to the complementary bases of nucleotides exposed along the halves of the unzipped DNA. This process creates two new DNA molecules, each with one strand of the original DNA molecule and one newly created strand.

The newly paired strands coil back into the double-helix shape as they are formed. Working from each one of the separated original DNA strands to make two new molecules makes DNA replication less prone to errors.

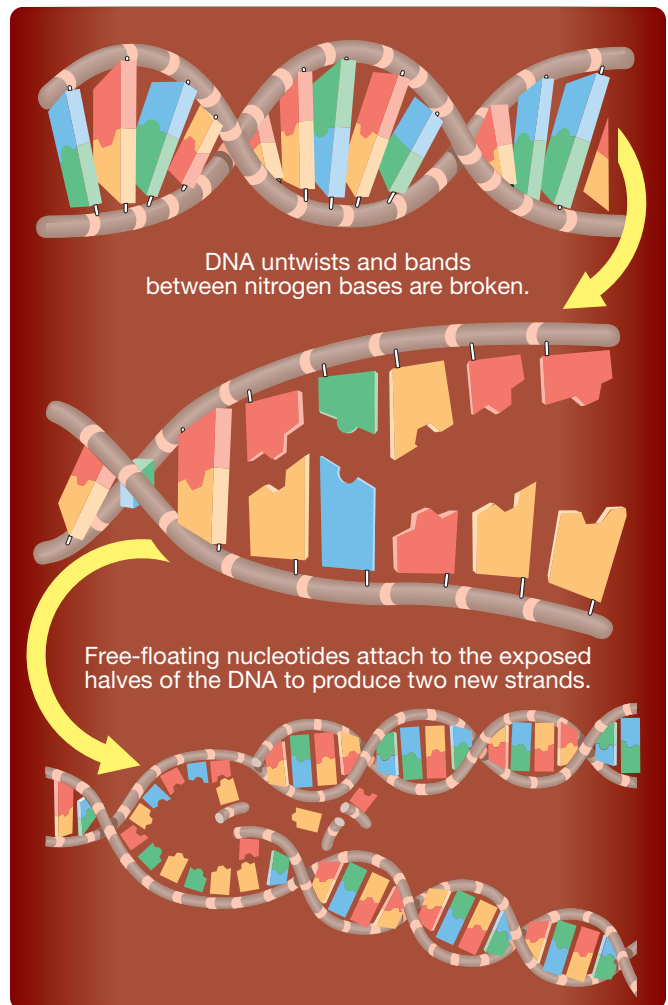


Figure A2.14

## The Genetic Code

You may have been surprised to discover that only four different nucleotides make up DNA. How can such complex instructions—like the gene to make a protein that helps to clot blood—be written by so few letters?

Think of how the many English words you read every day are all made up of different combinations of just 26 letters. The order in which these letters are put together, combined with the spaces and punctuation

between them, can form words, sentences, and instructions meaningful to the reader. Some forms of communication, such as musical notes, Morse code, or the binary language of computers, can be accomplished by using far fewer than 26 letters. Morse code, which is a series of dots and dashes, was used to pass messages along telegraph lines and until recently was used for visual communication between ships.

Binary language is made up of just two digits: 0 and 1. By using these two digits, a computer can be told how to carry out complicated operations. DNA code works on the same principle as other code systems. The arrangement of nucleotides on the DNA molecule creates a meaningful information sequence able to direct complicated processes in your cells.



DNA, sheet music, and cookbooks are all sets of instructions. The DNA molecule does not actually make proteins, any more than a sheet of music plays a song or a cookbook makes a cake. Products can be made by following the step-by-step instructions of a recipe, a sheet of music, or a gene.

Proteins are chain-like molecules composed of smaller units called **amino acids**. Amino acids are like the individual links in the protein chain or the ingredients that get put together to make a recipe. The instructions contained on the gene are written in three-letter groups, with each group acting like a word. Any combination of three of the four DNA nitrogen bases (adenine, cytosine, thymine, or guanine) forms a **DNA triplet code**. Each group of triplet bases stands for an amino acid. For example, the DNA triplet code AAA corresponds to the production of the lysine amino acid. The amino acid produced for each triplet is summarized in “DNA Triplet Codes and Their Corresponding Amino Acids.”

**amino acid:** one of the 20 possible building blocks of proteins determined by the genetic code of DNA

**DNA triplet code:** three adjacent nitrogen bases found on a gene that codes for the amino acid to be produced, begin, or end the reading of a gene

[illegible]

Nitrogen Base	Abbreviation
Adenine	A
Cytosine	C
Guanine	G
Thymine	T

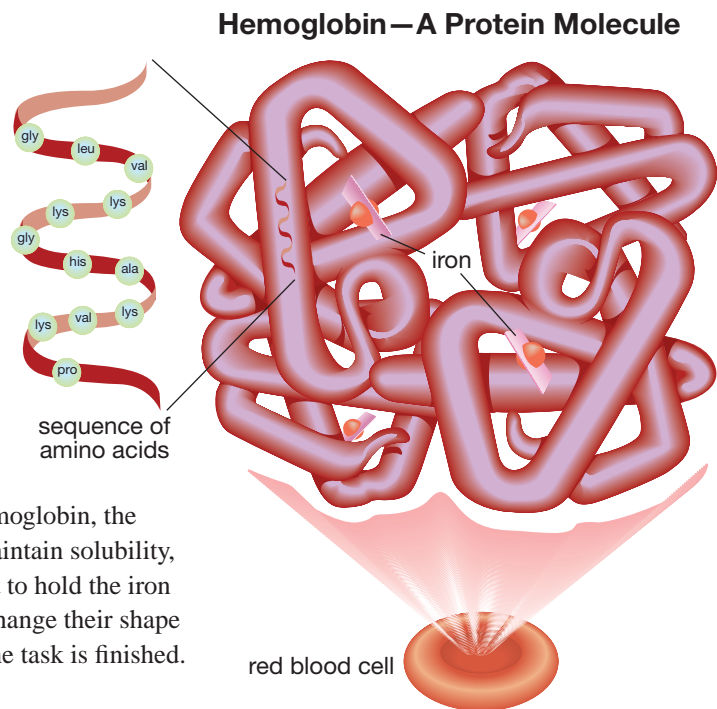
		SECOND BASE									
		T		C		A		G			
FIRST BASE	T	TTT	Phenylalanine	TCT	Serine	TAT	Tyrosine	TGT	Cysteine	T	THIRD BASE
		TTC	Phenylalanine	TCC	Serine	TAC	Tyrosine	TGC	Cysteine	C	
		TTA	Leucine	TCA	Serine	TAA	STOP**	TGA	STOP**	A	
		TTG	Leucine		TCG	Serine	TAG	STOP**	TGG	Tryptophan	
	C	CTT	Leucine	CCT	Proline	CAT	Histidine	CGT	Arginine	T	
		CTC	Leucine	CCC	Proline	CAC	Histidine	CGC	Arginine	C	
		CTA	Leucine	CCA	Proline	CAA	Glutamine	CGA	Arginine	A	
		CTG	Leucine	CCG	Proline	CAG	Glutamine	CGG	Arginine	G	
	A	ATT	Isoleucine	ACT	Threonine	AAT	Asparagine	AGT	Serine	T	
		ATC	Isoleucine	ACC	Threonine	AAC	Asparagine	AGC	Serine	C	
		ATA	Isoleucine	ACA	Threonine	AAA	Lysine	AGA	Arginine	A	
		ATG	MET or START*	ACG	Threonine	AAG	Lysine	AGG	Arginine	G	
	G	GTT	Valine	GCT	Alanine	GAT	Asparate	GGT	Glycine	T	
		GTC	Valine	GCC	Alanine	GAC	Asparate	GGC	Glycine	C	
		GTA	Valine	GCA	Alanine	GAA	Glutamate	GGA	Glycine	A	
		GTG	Valine	GCG	Alanine	GAG	Glutamate	GGG	Glycine	G	

\*\* TAA, TAG, and TGA are terminator triplet codes.

## The Versatility of Proteins

Earlier in this unit you learned that proteins are molecules that serve a variety of useful and important bodily functions. Hemoglobin is the oxygen-carrying protein in red blood cells. Like every other protein, hemoglobin is a molecule composed of one or more chains of amino acids. The unique sequence of amino acids within this protein, combined with its particular coiled shape, accounts for the protein's distinct properties.

Proteins have one or more amino acid chains and are coiled into a variety of shapes. The versatility of an amino acid chain means that protein structure can take on a variety of forms to suit different body needs. The way that the chains of amino acids are folded and combined together determines the protein function. In the case of hemoglobin, the amino acids on the outside of the hemoglobin molecule maintain solubility, while special amino acids on the inside of the molecule act to hold the iron compounds that bind to oxygen. Some proteins can even change their shape to perform a task and return to their original shape when the task is finished.



### Practice

33. List the amino acid sequence that would be produced from the following base sequence found on a gene segment.
- ATAAAGCGACTTCCC
  - AGAGGGGGTCTAGCC
  - GTATTAGATTACGTTACA
34. Write a DNA sequence of bases that coded for the production of the following amino acid chains.
- Tryptophan-Phenylalanine-Tyrosine
  - Methionine-Glutamate-Aspartate
  - Glutamate-Methionine-Cysteine

## 2.3 Summary

Deoxyribonucleic acid, or DNA, is the molecule that contains the coded instructions for creating proteins. Genes are regions along the DNA that code for a specific protein. A nucleotide is a chemical unit made up of a phosphate, a deoxyribose sugar, and a nitrogen base.

There are four nitrogen bases: adenine, thymine, cytosine, and guanine. Adenine only bonds to thymine and cytosine only bonds to guanine (A-T or T-A and C-G or G-C). When one base is bonded with its complementary base, the two bases are called a base pair.

DNA structure is two strands of nucleotides attached by their complementary bases and twisted into a double-helix shape. DNA has to be wound very tightly to fit into the nucleus. The molecule must become very twisted and it gets wound around proteins—called histones—that act like spools. To replicate, DNA pulls apart and complementary free-floating nucleotides attach to the appropriate exposed bases of the strands to create two new molecules, each with half of the original DNA molecule.

Within a gene, the nitrogen bases are read as triplets. Each triplet provides information about the formation of a polypeptide chain of amino acids used to make proteins.

## Utilizing Technology

### Interpreting the Genetic Code



### Science Skills

✓ Performing and Recording

#### Purpose

To construct a sequence of amino acids, you will decipher the coding along a segment of DNA.

#### Procedure

Locate the applet called “DNA—The Genetic Material,” on the Science 30 Textbook CD. Follow the instructions.





## 2.3 Questions

### Knowledge

1. Indicate whether each of the following statements is true or false. If a statement is false, explain why.
  - a. A DNA triplet code is made up of three amino acids.
  - b. A DNA triplet code may code for the same amino acid as another DNA triplet code.
  - c. Adenine bases can only bond to cytosine bases.
  - d. A double helix is similar in shape to a spiral staircase.
  - e. Genes provide the instructions to make proteins.
  - f. There are ten different amino acids.
  - g. Histone is one of the four base pairs found along the DNA molecule.
  - h. Alternating phosphate and deoxyribose sugar make up the backbone of a DNA strand with the base pairs attached in the middle.
  - i. During replication, the DNA breaks into small pieces and re-forms as two smaller halves.
  - j. A DNA molecule has three strands of nucleotides braided together.

### Applying Concepts

2. Use the “DNA Triplet Codes and Their Corresponding Amino Acids” table to determine which of the following DNA sequences would code for the production of valine-alanine-asparagine.
  - I. AAAAGAATA
  - II. CATCGCACA
  - III. GTGGCTAAT
3. Draw a series of diagrams to show how DNA is replicated. Use two colours to distinguish between the original DNA strands and the newly produced DNA strands.
4. Like every other protein, hemoglobin consists of chains of amino acids. The sequence of amino acids in one section of a hemoglobin molecule is Glycine-Leucine-Valine . . . . Determine the corresponding DNA triplet codes that would provide the instructions for building the first three amino acids in this sequence.
5. Complete the following table that compares protein synthesis to making a cake from a recipe.

Making a Cake	Protein Synthesis
• a library of cookbooks	• a karyotype of all the chromosomes for one individual
• a cookbook of recipes	
• a recipe for a particular cake	
• the words of the recipe	
• ingredients that go into the cake	
• the finished cake product	